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Mine safety enhancement by designing dynamic rock supports

D. Raju^a, Hani Mitri^a, Denis Thibodeau^b^aMcGill University, 3450 University street, Montreal, H3A 2A7, CANADA^bVale Ltd, Sudbury, Ontario, CANADA P0M 1N0

Abstract

Despite the developments in all aspects of the mining industry, mining fatalities are still occurring in all parts of the world every year. Ground falls occur due to bad ground/ geological conditions and high stress environments in deep hard rock mines. It is therefore important to design support systems that will hold or retain the rock mass in place and prevent their falls. Stability and safety are of utmost importance to a mining operation. This paper presents a review of Canadian practices of supporting these types of ground conditions, and a proposed methodology for designing dynamic rock supports. This methodology is based on the estimation of the stored induced energy around the mine opening in high stress conditions through numerical modelling as well as post failure studies in the laboratory using stiff testing machine. The role of instrumentation is also reviewed in monitoring the effectiveness of the support system.

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1. Introduction

Mine safety is directly related to the efficacy of the support system designed for particular mine opening. Knowledge of the rockmass behavior in general, and the failure process and the strength in particular, is important for the design of mine openings, tunnels and caverns. Keeping in mind the long service life of the haulage drifts and the purpose they serve, the stability and safety of these openings are of utmost importance to a mining operation. The design of underground openings is generally based on empirical and intuitive approaches. Empirical design methods are based on ratings assigned to underground openings. These ratings are based on estimates of rock strength, characteristics of discontinuities, seepage etc. Some of them can only be determined after opening an excavation. These

* Corresponding author. Tel.: +1 514 398 4890; fax: +1 514 398 7396.

E-mail address: guntumadugu.raju@mail.mcgill.ca

empirical methods do not account for the in-situ stresses, direction of discontinuities, etc. Application of principles of rock mechanics, and numerical modeling would lead to development of a qualitative and quantitative approach for design of effective underground openings

2. General practice

Support design for mines and tunnels is generally based on empirical methods. The major problem in rock engineering compared to other engineering branches is the inherent uncertainty and complex, inhomogeneous behaviour of the rock material. The extent to which one can overcome the difficulties depends on the geological conditions, which exists on site and the extent to which one can take them in to account. The geological data such as type of rock, joint patterns, dip and strike can be collected from the borehole investigations for different projects. These inputs are used in calculating 'Q' or 'RMR' based on which the support system is estimated in most of the cases.

2.1. Site specific innovative methods

In addition to the general practice of designing supports as mentioned above, some site specific innovative methods were also devised and applied successfully for burst-prone areas. One such method is developed and applied successfully for the burst-prone areas in Vale's Copper Cliff North Mine in Sudbury operations[1]. The approach adopted here was risk based approach to design highly yielding support to sustain future seismic impact after gaining experience from the major rockburst. A risk rating system to determine where enhanced support system is required was evolved by taking the following six parameters in to consideration and then assigning numerical rating to the parameters.

- Historic Seismic data of the area
- Ground condition
- Efficacy of the existing ground support
- Deteriorated infrastructures in the proximity
- Anticipated mining induced stress
- Other geological structures in the proximity

The total risk rating will be arrived after summing up the individual ratings. The threshold rating of the risk is established after back analysis of number of areas within the mine. If the total risk rating crosses this threshold rating, then enhanced support is required in the form of yielding supports in that area. Also the type of enhanced support is determined using the five step methodology [1]. Typical burst prone area; supported using this methodology is shown in Figure 1.



Figure 1. Enhanced supports installed in burst prone areas (after Yao et al, 2009)

3. Need for dynamic supports

As the mining depth increases, mine openings at great depths will often become unstable due to the fact that the rockmass is subjected to high stresses. Such instabilities must be controlled by adopting appropriate support measures to control the falling rockmass to maintain safe workings. In such conditions managing the damage due to mining induced seismicity by appropriate energy absorbing support systems forms key factor. [2] Make it clear that the design of such support system requires consideration of the nature of seismic hazard, the additional demand placed on the support by dynamic forces and the capacity of the support system to meet that demand.

The effectiveness of the support system for the particular condition is the deciding factor in achieving the safe mining conditions. Conventional support design methodologies utilize empirical rock mass classification systems to design the supports, which work for a static conditions. However, in burst prone environment, conventional support design methods are not suitable as dynamic conditions or pseudo dynamic conditions (large deformations) prevail. The supports for these conditions require yielding /energy absorption capabilities to have stable and safe working conditions. A design methodology involving a rational approach will be able to serve this purpose. Also it is appropriate to look into the characteristics of the support system, both static and dynamic and match with the all support elements in a particular support system.

3.1. Support characteristics

It is also important that one considers both static conditions (supporting the weight of the surrounding rock with rigid ground support elements) and dynamic conditions (surviving additional forces, energy absorption, which may be imposed suddenly and without warning through using yielding ground support systems).

The static behavior of most support elements has been widely investigated and documented over the years [3]. As mining depths increase and mine openings are made in high stress conditions, rock burst phenomena become imminent. Due to this fact the dynamic characteristics of the ground support are becoming important parameters for the design and selection of yielding support systems for over stressed rock. [4] Explain the function of each element in a support system and note that it depends on its interaction with the ground. The Canadian rock burst research program (CRRP) [5] explains the three primary functions of the support elements, namely, reinforcing, holding and retaining. Reinforcing mechanisms generally restrict and control the bulking of the rockmass. Typically reinforcing elements such as grouted rebars or dowels behave as stiff support elements.

Whereas split set bolts, yielding Swellex or cone bolts, yield lock bolt, D-bolt may behave as ductile or yielding elements under high stress or deformation conditions. The holding function is to tie the retaining elements of the support system and loose rock back to stable ground. A mechanical rock bolt performs the holding function. The dynamic characteristics of some of the support systems are shown in Figure 2 and Figure 3.

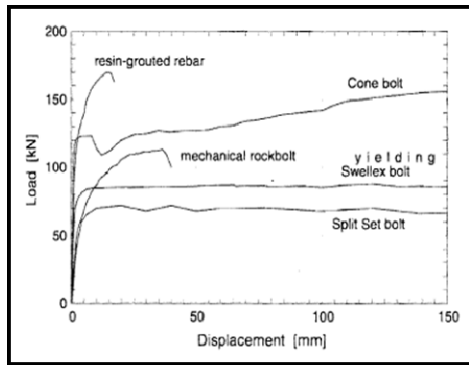


Figure 2. Load-displacement Characteristics of Holding And reinforcing elements (after Hoek, 1995)

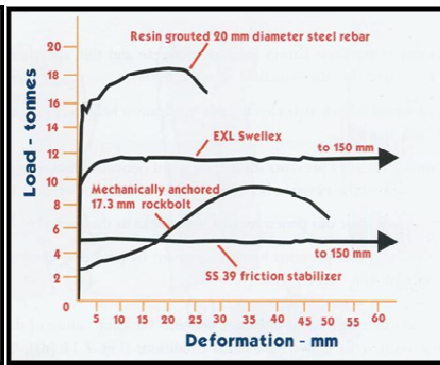


Figure 3. Load displacement characteristics of Holding and Reinforcing elements including Cone bolt (after CRRP 1996)

It can be seen from figure 2 that resin grouted steel rebar is good in holding the rock and is very poor in dynamic conditions. On the other hand Swellex and friction stabilisers are taking load as well as deforming to counter the dynamic events. Both the tests above show same results. However, CRRP,1996 includes the Cone bolt also, which is widely used in Canada for the burst prone ground support. It can be seen from figure 3 that the cone bolt seems to be promising option, in that it is taking 150kN load and also yielding to 150mm. One more characteristic that is important in dynamic supports is energy absorption capacity. Figure 4 shows the results of energy capacities for some of the support elements. Again it can be seen that the resin grouted rebar and mechanical rock bolt have got less energy absorption capacity. Whereas the other supports like cone bolt , Swellex and split set bolts are able to absorb high energy capacities, which is required during a rock burst.

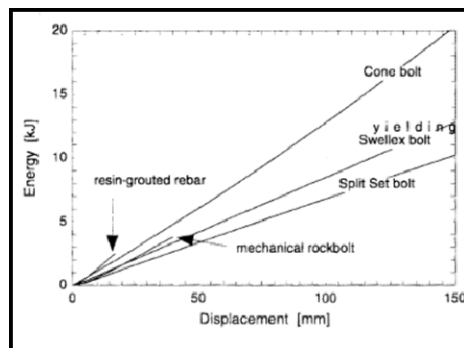


Figure 4. Energy-displacement curves for reinforcing and holding elements (after CRRP 1996)

3.2. Dynamic support selection

It is evident from the previous sections that now we have variety of supports which have got dynamic characteristics available in the industry. There is a lack of a rational methodology to select appropriate dynamic support capacity that can be used for any mine to contain the rock falling out of dynamic event such as rockburst. As a result several Canadian mines have devised their own methodology for selecting the yielding support for the dynamic conditions. All these methods are based on the information after the

opening is made and after gaining sufficient experience from the previous rockburst events. It will be useful to have support selection methodology for specific opening shape and size before it is opened. In the following sections the typical drift support systems used in Canadian mines is described and then the proposed methodology for selection of dynamic supports is presented.

4. Typical drift support systems in Canadian mines

Drift supports are installed in two phases as primary supports and secondary or enhanced supports. Primary supports are installed during the initial stages of mining and the secondary or enhanced support systems are installed when the drift openings intersect with other drifts and when nearby mining activity takes place causing multiple openings. Primary support systems in Canadian mines typically employ 3/4 inch resin grouted rebar in the back and shoulder. In low stress, jointed/fractured rock mass for short term openings (2 year life or less), the efficiency of resin grout is not warranted, hence the use of 5/8 inch and 3/4 inch mechanical rockbolts with expansion shell. Typical support length is 6 to 7 feet (1.8 to 2.1 m) for drifts of spans in the range of 4 to 5 m. On the other hand, sidewall support systems employ more ductile support such as Swellex and SplitSets. These supports offer greater ability to accommodate sidewall deformations due to mining-induced convergence. A typical primary and secondary support systems practiced at some of the mines in Canada, where a high horizontal stress causes the instability are shown in Figure 5 and Figure 6.

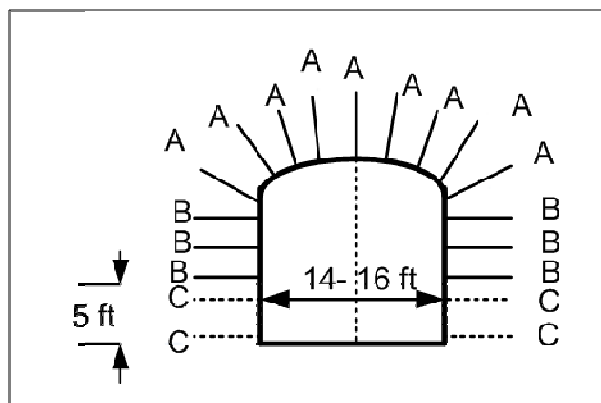


Figure 5. Primary support system during regular rock development and in Ore development

	Excavation width < 18 ft		Excavation width > 18ft	
Regular Rock Development	A	6-ft rebar	A	8-ft rebar
	B	6-ft rebar	B	6-ft rebar
	C	*	C	*
Development in Ore	A	6-ft rebar	A	8-ft rebar
	B	6-ft 6-inch FS46 Split-Set	B	6-ft 6-inch FS46 Split-Set
	C	*	C	*

* Development requiring lower wall support, is applied as follows: Stope sills, Diamond drill stations, Raisebore stations, Shotcrete headings; where shotcrete is required to the floor, and all other excavations.

As can be seen from figure 5, it is evident that the rebar of various lengths is the predominant support system during the regular rock development where no difficult ground conditions exist. In the ore development the primary support system consists of split sets. The secondary or enhanced support system consists of 8ft long Modified cone bolt(MCB) or MN12 Swellex bolt along with '0' gage mine mesh as shown in figure 6. It is understood that the secondary or enhanced support system has the yielding capacity to counter the dynamic activity. This sort of support system will enhance the mine safety during the difficult ground conditions. Apart from this reinforced shotcrete with o mesh or with steel fibers is also employed to have a safe back and walls.

Another type of support system that is used in Canada, where the stresses are not the root cause of the instability but the "pseudo dynamic behaviour" because the rock mass is highly foliated and weak. Once the opening is made the sidewalls converge. There are no or little tectonic activities, and the concern is high deformation and roof caving due to slip along the planes of weakness. The typical support system for this type of ground conditions is shown in Figure 7. Mine development in some of the mines is in the hanging wall. Ground support system for drifts in the host rock include roof supports in two staggered rows that are 60 cm apart, one row is made up of four 7 feet - 6 inch long rebars or 10ft long Swellex Mn 12, and another is made of five 6 foot 2 inch long rebars. Sidewall support starts from the shoulder down, with 5 ft long friction sets in a diamond pattern of 60 cm x 60 cm spacing. Welded wire mesh is no. 7. The drifts are 4 to 6.5 m wide, and 4 to 5 m high. Wire mesh covers the top part of the sidewall - the bottom 1.8 m is not covered with the wire mesh and is shown in figure 6. And the support system for the drifts driven in the ore such as sill drifts consists of friction sets all the way to the bottom of the sidewall (60 cm from the floor). Wiremesh #6 or 7, and it covers the entire sidewall. The size of the drifts will have variable width from 3.5 to 6.5 m (depending on ore thickness) and is shown in figure 8.

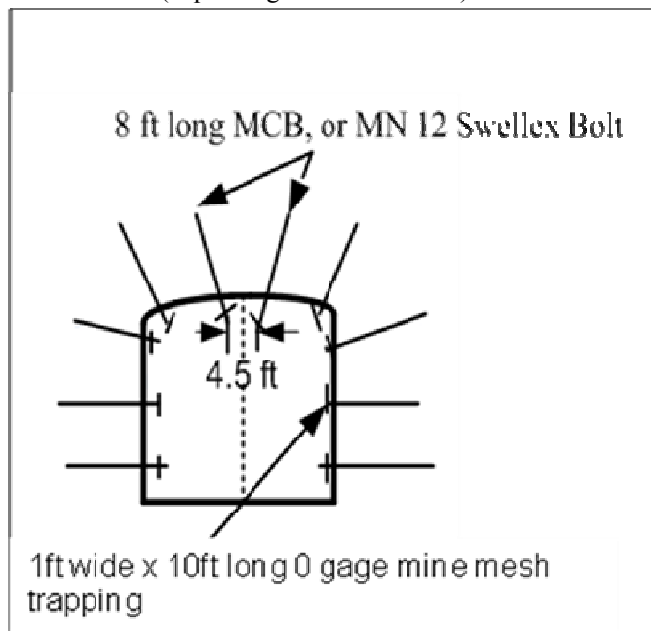


Figure 6. Secondary or enhanced support system during regular rock development and in Ore development

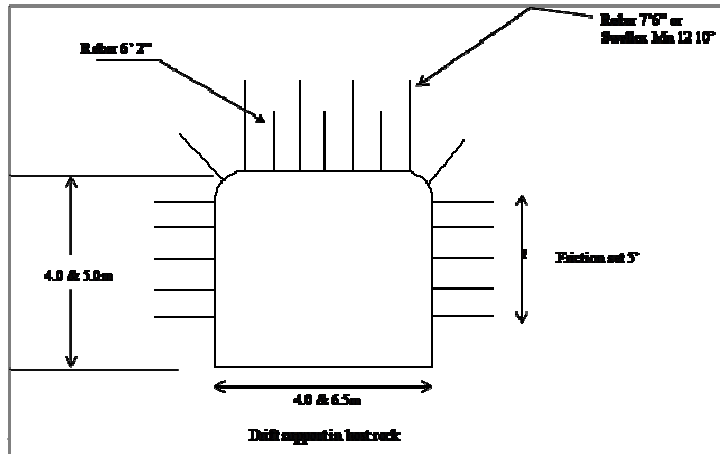


Figure 7. Typical ground support in drifts driven in host rock

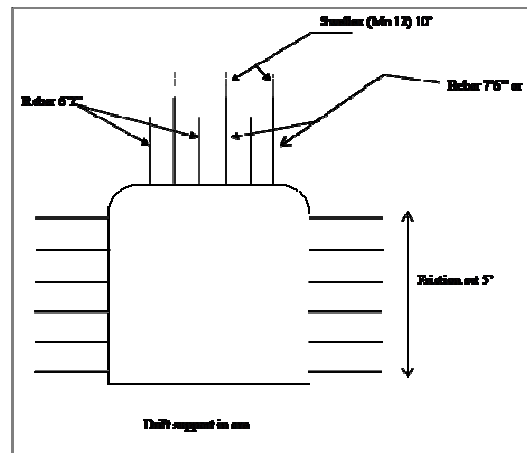


Figure 8. Typical ground support in drifts driven in ore (sill drifts)

It can be seen from the above support practices that, the supports are designed carefully taking in to account the anticipated ground behavior and accordingly the yield supports are being provided wherever necessary. This practice of designing supports for varying strata requirements within the drift improves the stability of the opening dramatically and provides safe working conditions for men and machinery. However, the yielding capacity of the supports that are provided may be decided on the previous experiences or in some cases may be through numerical modeling approach. It is insisted that these yielding requirements in the dynamic supports for particular openings need to be rationally estimated. Moreover this estimation of yield capacity requirements such as energy absorption and displacement for the particular openings should be carried out before excavating that particular opening. This approach will prepare the mine management in advance to plan for the appropriate support system that should be employed in those areas and can ensure the safe working conditions during the mining operations.

5. Proposed methodology

The proposed methodology for design of dynamic rock supports in burst prone ground is based on estimation of the stored/induced energy around the opening for both strain burst conditions and seismic wave propagation due to fault-slip events through numerical modeling and, post failure studies in the laboratory using stiff testing machine. The present approach permits the calculation of mining-induced energy stored in the rock mass. Following the line of thought that rockburst is due to sudden release of energy from a volume of highly stressed rock, it can be supposed that violent failure will take place when the energy stored in the rockmass exceeds a critical value, thus rendering the rock material to its post-peak (unstable) range [6]. On this lines of Energy Storage Rate (ESR) and Critical energy stored in the rockmass (e_c), [6] proposed Burst Potential Index (BPI) of the surroundings of the particular opening.

Burst Potential Index(BPI) is defined as

$$BPI = \frac{ESR}{\sigma_c} \times 100\%$$

Where

ESR = Total mining induced strain energy stored in the rock mass
 e_c = Critical strain energy storage capacity of the rock

Thus the burst potential index is a function of the energy storage rate (ESR) of the rock mass and the critical strain energy storage capacity of the rock. Mitri et al. (1996) also provide equations to estimate ESR and e_c as given below.

$$ESR = \frac{1}{2E_{RM}} \times (\sigma_1^2 - \sigma_0^2)$$

$$e_c = \frac{1}{2E_{RM}} \times \sigma_c^2$$

where

E_{RM} = Modulus of elasticity of the rock mass

σ_1 = Mining induced stresses

σ_0 = Initial (in situ) stresses

σ_c = Uniaxial compressive strength of the rock

In a simple uniaxial test, the critical energy density value, e_c , can be defined as the area under the stress strain curve up to the point of peak stress, as shown in figure 9.

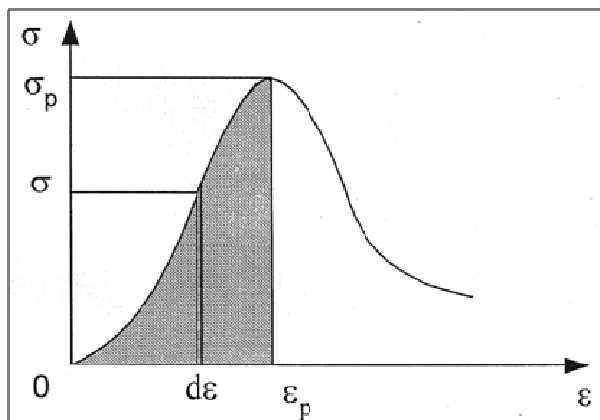


Figure 9. Definition of critical energy stored in a uniaxial test (after Mitri et al., 1996)

Using the BPI and numerical modeling, the amount of energy stored, likely displacements and the overall burst proneness of the surroundings of the opening can be evaluated for any particular opening in the present method. Once the amount of energy that will be released during any event is known and the deformations of the walls and the back are also known through modeling, one can select the appropriate energy and displacement (yielding) capacities of the support system for that ground condition. However the energy estimated here may be over evaluated as all the energy available may not be utilized in rock displacement, which may lead to over designed supports. This can be overcome by back analyzing the previous events. The flow chart showing the proposed methodology is presented in Figure 10.

5.1. Numerical modeling

An example of the energy distribution around the drift from numerical modeling due to the nearby mining for a typical drift is shown in Figure 11. In the same way the displacements of the walls and the back of the drift can be predicted using the numerical modeling. The model geometry is shown in Figure 11(a). It can be seen from this figure that the drift is of 5mx5m size and the nearby stopes are 10x30m and the distance between the drift and the nearby stopes is 25m. In this simulation, the drift is excavated first and then the nearby primary stope is excavated followed by backfilling the excavated stope before excavating the secondary stope. Figure 11(b) shows the energy distribution around drift after the drift and the first stope have been excavated. It can be observed from this example that the energy distribution is changing around the drift as the mining progress both in magnitude and location. Such energy changes can be used to assess the stored energy ESR and hence the burst potential index (BPI) as defined above. It can also be used as a basis for support selection with respect to their energy absorption capabilities.

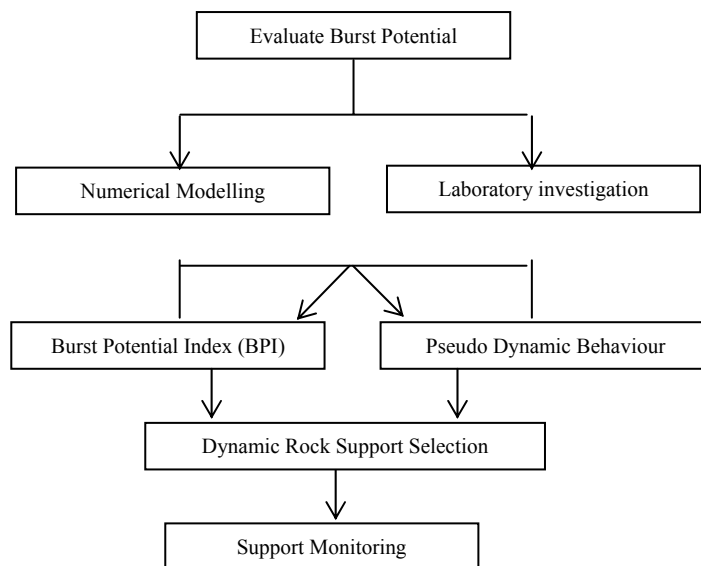


Figure 10. Flowchart showing the steps in methodology for dynamic support design

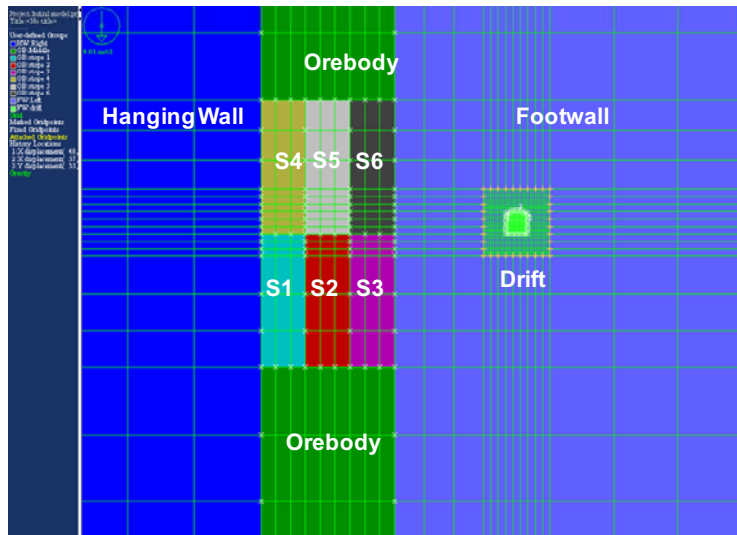
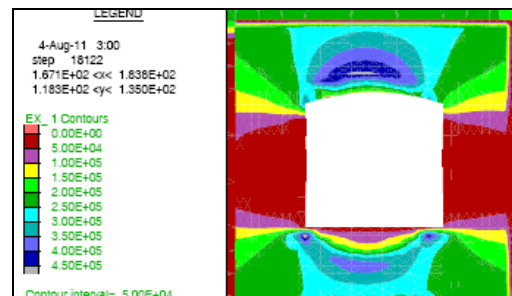


Figure 11(a). Model geometry

Figure 11b. Energy distribution in J/m^2 after mining of first stope

5.2. Instrumentation

In dealing with the burst prone grounds, much attention is given to the design and installation of adequate rock supports with yielding capacity. Rock supports in the form of rockbolts of various types are installed in almost all of the mine access areas [7]. The role of these rock supports are very important as a primary support, it is necessary to verify that the rockbolt is functioning adequately and is not subjected to excessive load. There are many situations where such a concern may arise especially in development and production areas where the ground response changes constantly due to mining induced stress changes. On the other hand the walls and back converge due to various reasons as the mining progresses. It is also essential to monitor the strata behavior with respect to the nearby mining and also in response to the installed support system.

The new measurement techniques for monitoring both bolt load and deformation were successfully developed and became commercially available. Monitoring axial load on rock bolts were made easy with invention of U-Cell (coupler load cell) [7]. This new bolt load monitoring device is coupled with the rockbolt itself and there by relieving from the installation difficulties, handling and maintaining of bulky

hollow load cells. See [7] for the details of design concept and performance of U-Cell. Figure 12 shows the installation of the new coupler load cell in the field to monitor bolt axial load in a deep hard rock mine. Monitoring the deformations around the openings can be performed by utilizing the remote type Multipoint Borehole Extensometers (MPBX).



Figure 12(a). U-Cell ready to install



Figure 12(b). U-Cell installed in the wall of a drift

6. Conclusions

Underground openings, in general warrant for ground support to improve stability and to ensure a safe working conditions for both the persons and the machinery. It is well known fact that the majority of the fatalities in most of the underground mines are due to roof/side falls. By adopting the appropriate ground supports design, most of the roof falls can be averted. The design of the supports and their characteristics should be in line with the anticipated rockmass behavior (both static and dynamic).

Load changes on rock support because the mine environment is constantly changing, and hence there is a need to base the rock support design on dynamic behavior. Though the efforts have been started in this direction, still there is a lack of dynamic support design criteria in the literature. The performance of the proposed design need to verify using appropriate geotechnical instruments such as U-cell (for monitoring the axial load on bolt head) and MPBX (for monitoring the deformations in wall and back). The energy and displacement characteristics of most of the support elements are known and available in the literature. The rational methodology of predicting the energy and displacements around opening and selecting appropriate supports will help the user to select the appropriate support to deal with the adverse ground conditions and thereby ensuring the safe working conditions.

Acknowledgements

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